1-1-1973

Application of nuclear technology to different countries

Narisa Nan-Yee Chu
Iowa State University

Application of nuclear technology
to different countries

by

Narisa Nan-Yee Chu

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE

Department: Chemical Engineering and Nuclear Engineering
Major: Nuclear Engineering

Iowa State University
Ames, Iowa

1973

TABLE OF CONTENTS

DEDICATION

To Francis

I. INTRODUCTION

The objective of this thesis is to determine the relationships among the factors influencing the application of nuclear technology so that it will be used effectively and economically in a country, especially in developing ones. Factors of geography, economics and society are taken into consideration. As used in this thesis, nuclear technology consists of different ways of using nuclear energy, such as nuclear power for electricity and desalination, and radioisotope utilization in agriculture and industry. Developing countries are those with per capita income averaging less than $500. Most of the countries of Africa, Asia, and Latin America, and Greece, Portugal, and Spain are generally considered developing (25).

At the present time, nuclear power stations are in operation in only two developing countries--one is India, the other is Pakistan. Nuclear power plants are under construction in five additional developing countries: Argentina, Brazil, Bulgaria, Korea and Taiwan; eight more (Greece, Hungary, Mexico, the Philippines, Romania, Thailand, Turkey and Yugoslavia) are actively planning to introduce nuclear power, and several others are thinking of introducing nuclear power in the long term. Altogether there are 20 to 25 developing countries actively interested in nuclear power programs and are making preparation for its introduction (10).

What is the justification for nuclear technology in developing countries? Why should they consider nuclear technology?

The main reason is economic--because it is only through having adequate and reasonably priced power that the developing countries can hope to implement their industrialization and development programs.

Several methods of calculation for electricity and water prices using a nuclear power plant have been developed (2, 16, 19, 20). The emphasis in this thesis is on how the overall environment affects the benefits from nuclear technology of not only nuclear power production but also radioisotope utilization.

There are three groups of factors involved.

1. Natural environment, such as conditions of geography, geology, resources, population, agriculture, import, export, domestic market, electricity, labor, wages, interest rate, as well as educational level of the people, all serving as input factors.

2. Nuclear technology, such as nuclear fission in production of electricity; nuclear power for desalination; radioisotope studies on soil structure and hydrology, fertilizer application, breeding of new varieties in agriculture; food preservation by sprout inhibition, insect disinfestation, growth inhibition, and basic metals industry.

3. Benefits, the dependent variable including profit from immediate sale of products, labor saved, time saved, and opportunities created.

The whole procedure in this thesis is divided into two steps. First, take land, labor, available capital, operation and maintenance, safety, public acceptance, interest rate and factory life time into consideration. The influence of these factors on agricultural and industrial productivity through nuclear process upon benefits gained by a society is evaluated.

The second step has the same format as the first one, except considering only products directly out of the factory after the raw materials feed in, no delay in growth, transportation and transformation later on.

Figure 1 helps to envisage these two steps.

In brief, this work is divided into three major parts. The first part starting from realizing the importance of nuclear technology to developing countries (Chapter II) to further evaluate some significant factors which will affect the benefit in a country (Chapter III).

Dimensional analysis is used in the second part (Chapter IV) particularly to find π-terms and the benefit equation is thereafter determined (Chapter V) and more thoroughly discussed (Chapter VI).

Finally, a benefit formula is applied to two case studies of India and Taiwan (Chapter VII) and a comparison is made (Chapter VIII).

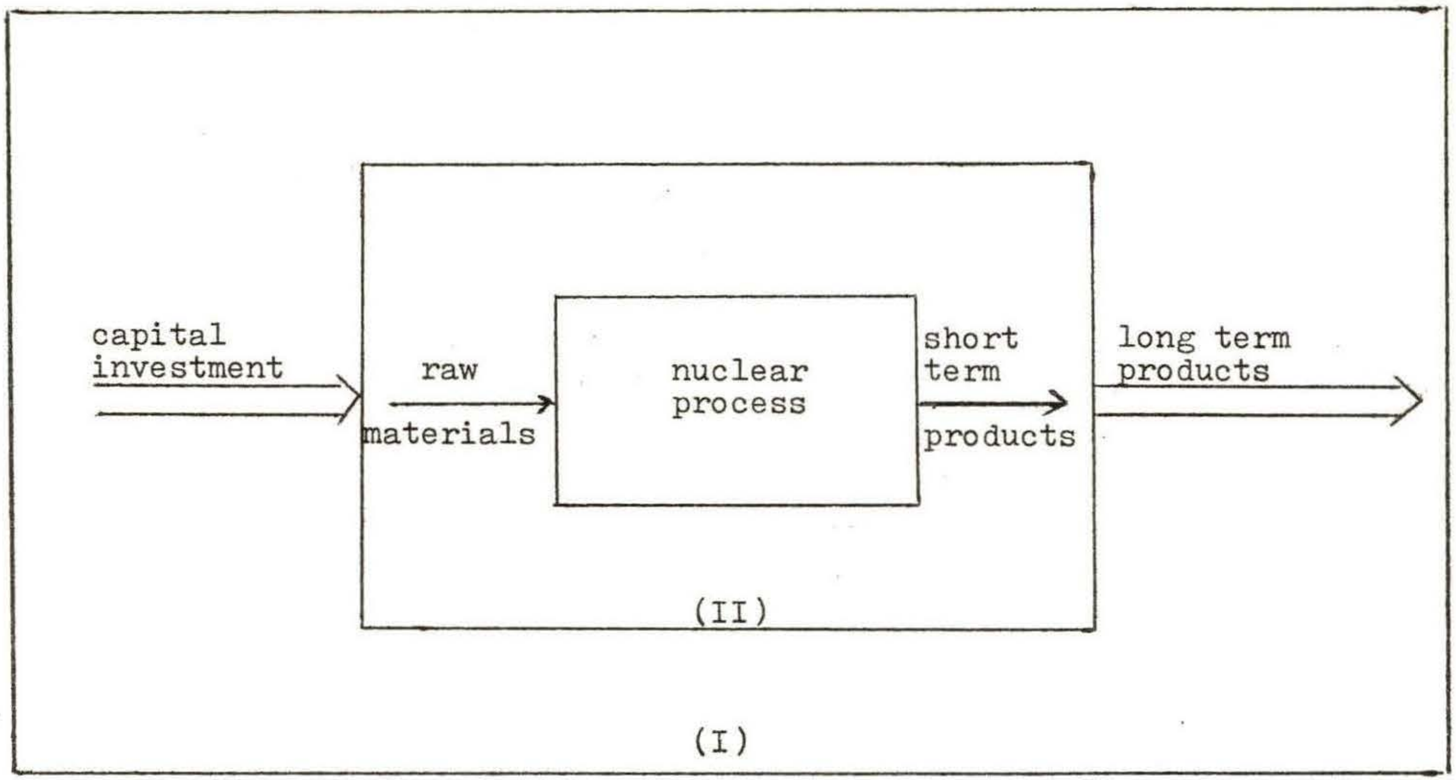

Figure 1. Two steps of determining overall benefits

II. IMPORTANCE OF NUCLEAR TECHNOLOGY TO DEVELOPING COUNTRIES

Comparison between the overall power programs of developed and developing countries shows that at the present time developing countries account for only about 2 percent of the world nuclear generating capacity, which is estimated to rise to about 9 percent by 1980. By 1985, when an estimated 23 percent of the generating capacity of industrialized countries would be nuclear-powered, the corresponding percentage would be only about half as much in the developing countries. Projections for the year 2000 show that at that time about half of all installed capacity in the industrialized countries will be nuclear-powered, but in developing countries, nuclear power will account for only about 20 percent (10, 13). It is the electricity that implements the industrialization and development of a country. It is obvious that nuclear power technology, instead of serving to close the gap between the advanced and the developing countries, is in practice only widening this disparity.

Most developing countries are much more agricultural than industrialized. The handicaps in agriculture together with desiring industrial promotion enhance the possibilities of utilization of nuclear energy. The handicaps are:

1. Lack of energy; industrial development requires a large amount of electricity. The annual increase in the rate of use of electricity in most developing countries is over 10%.

2. In most cases, the soil is highly eroded, poor in structure and lacking in major nutrients.

3. Water resources are not properly tapped and scientifically utilized. Poor moisture conservation practices turn to great-risk farming and yield instability.

4. The size of an average farm is small and fragmented.

5. The cereal varieties usually cultivated are season-bound. The cropping systems are usually used only for home needs rather than the market. They are chosen for their ability to withstand poor growing conditions, particularly the incidence of pests and also poor processing and storage arrangements.

6. Animal husbandry has remained isolated from agriculture.

7. Agriculture is regarded as a profession for unskilled labor and not requiring any intellectual input.

8. Explosive population growth (13, 18).

Under a situation like this, suggested nuclear fields are:

1. Nuclear power plants to produce electricity which is an essential ingredient for increasing productivity in agriculture as in industry.

2. Nuclear desalting plants to provide energy and water which are two of man's most fundamental needs. Further, such plants open more land to produce more food in meeting growing population.

3. Irradiation facilities for sterilization of medical supplies, food preservation, wood-plastic composites manufacture, chemical synthesis and plastics modification processes, large-scale sewage treatment and manufacture of concrete polymer composites.

4. Nuclear tools in agriculture

   a. Studies on soil structure in relation to nutrient uptake and crop growth;
   b. Increasing the efficiency of water use;
   c. Improving the efficiency of nutrient supply to crops;
   d. Increasing the uptake of P by means of phosphorus-solubilizing bacteria;
   e. Matching nutrient supply techniques to weather conditions;
   f. Developing efficient cropping systems;
   g. Radiations and radioisotopes in the design and breeding of new crop ideotypes;
   h. Nuclear techniques as analytical tools in improving protein and oil content of crops;
   i. Plant protection efforts to match the increasing production potential of the major food crops;
   j. Avoiding spoilage and storage losses;
   k. Isotopes and radiation in animal research;
   l. Isotope technology provides the industry with approach in materials analysis and handling,

process measurement and optimization, quality control and solving of processing difficulties (1, 3, 4, 7, 8, 9, 16, 18, 21).

III. SIGNIFICANT FACTORS IN A COUNTRY

Countries differ in factors of geographical distribution, economical situation and social structure. According to its characteristics, application of nuclear techniques may bring completely different results to one country in contrast to others.

For example: a nuclear dual-purpose plant could be established in an undeveloped area in an advanced nation for international implications. Places in the southwestern United States, the Soviet Union, or Australia are suitable. On the other hand, a dual-purpose nuclear plant may be built in an undeveloped area of a large less-developed nation, such as Communist China, India, or in an undeveloped region involving several small countries, such as the Middle East. The reason is that there is a trend toward larger and larger generating units of nuclear stations owing to their capacity for reducing costs per kilowatt hour of electricity produced or per cubic meter of water desalted. A large amount of electricity and water produced at low cost would stimulate agricultural or industrial productivity, and would significantly increase the national outputs of the food and industrial products concerned. In fact, few less-developed nations would have an existing domestic market large enough and organized so as to be able to absorb the output efficiently, and the transition from no production to full production would be abrupt as far as the social structure and environmental problems are concerned.

Some countries are bothered by mass invasions of pests to crops, others are worried about lack of food. Radioisotopes provide a new method to improve situations like these in pest infestation, food preservation and creation of better varieties of crops. As a whole, the supply and transportation of primary energy resources, the wages of labor force, the brain power, the cost of money, the availability of capital currency, etc., all influence the decision of whether or not to introduce nuclear technology.

As to the nuclear facility itself, the expected lifetime is a basis for setting up the provisions for depreciation and it therefore influences the total capital investment. In an electric system, power stations are operated according to their order of merit to meet the fluctuations in the demand. Hence, the plant factor becomes significant.

From the foregoing considerations, the significant factors are as summarized in Table 1 together with their symbols, dimensions, and measurements. These factors give an idea to decide qualitatively whether to use nuclear technology or not. Further investigation of factors such as labor force (N_L), number of technical personnel (N_e), natural resources (R), export surplus (E_x - I), interest rate (r_i), annual energy consumption (E_c), station load factor (L_f), and station life time (n), contributes to a quantitative expression indicating

Table 1. Significant variables and their symbols, dimensions, and measurements

Symbol	Factor	Dimensions[a]	Measurement
B	Benefit	Y	\$
N_t	Total population	-	# of persons
N_L	Labor force	-	# of persons
N_e	Technical staff	-	# of persons
w	Wages	YT^{-1}	\$/person/month
A_t	Total area	L^2	$miles^2$
A_a	Area of arable land	L^2	$miles^2$
A_m	Area of mountains	L^2	$miles^2$
A_d	Area of desert	L^2	$miles^2$
A_r	Area of rivers and lakes	L^2	$miles^2$
A_s	Length of seashore	L	miles
c_A	Unit cost of land	YL^{-2}	$\$/mile^2$
c_W	Unit cost of water	YL^{-3}	$\$/m^3$
R_f	Annual rainfall	L	inches
T_m	Yearly mean temperature	-	^oF
R	Natural resources (uranium, coal, petroleum, natural gas, etc.)	F	tons
c_R	Market price of natural resources	YF^{-1}	\$/ton
P_A	Annual total agricultural productivity	YT^{-1}	\$/yr

[a]Y represents the dimension of money; T represents the dimention of time; L represents the dimension of length; F represents the dimension of force.

Table 1. (Continued)

Symbol	Factor	Dimensions	Measurement
P_I	Annual total industrial productivity	YT^{-1}	\$/yr
c_F	Unit food price	YF^{-1}	\$/ton
H	Market animals	-	head
f	Fishing	F	tons
F_r	National potential of forest	L^2	feet^2
F_t	Timber production	L^3	feet^3
c_P	Unit wood price	YL^{-3}	\$/feet^3
I	Import, annually	YT^{-1}	\$/yr
E_x	Export, annually	YT^{-1}	\$/yr
G	Gross national income	YT^{-1}	\$/yr
I_P	Per capita income	YT^{-1}	\$/person/yr
r	Annual economic growth rate	T^{-1}	%/yr
r_i	Interest rate	T^{-1}	%/yr
E_m	Employment = $\frac{\text{labor force}}{\text{employable population}}$	-	%
U_c	Public acceptance = $\frac{\text{\# of people accepting nuclear facilities}}{\text{Total population}}$	-	%
E_c	Annual energy consumption	FL	Gwh/yr
E_t	Total electric system capacity	FL	Mw
c_E	Unit electricity price	$YF^{-1}L^{-1}T^{-1}$	mills/kwh
L_f	Station load factor	-	%

Table 1. (Continued)

Symbol	Factor	Dimensions	Measurement
r_e	Electricity growth rate	T^{-1}	%/yr
T_h	Total length of highway	L	miles
T_r	Total length of railroad	L	miles
N_p	Airports	-	# of airports
N_h	Harbors	-	# of harbors
c_s	Transportation cost	$YF^{-1}L^{-1}$	$/ton/mile
n	Station life time	T	yr

the benefit.

1. B Benefit [Y][1] ($)[2]

Benefit from nuclear process can be resolved into several components:

a. Direct benefit: (sale of products from nuclear facility) - (expenditure on nuclear facility).

b. Indirect benefit:

(1) Labor saved; measured by (# of laborers saved) x (average wage/laborer) in terms of $

(2) Time saved; measured by (time saved) x (dollar equivalent/time) in terms of $

[1]Inside brackets shows dimensions.

[2]Inside parentheses shows the unit of measurement.

(3) Stimulation of other business; measured by increase of agricultural or industrial products which can be expressed in equivalent dollar value of total products.

2.	L	Labor cost $= \sum_{i=1}^{5} N_i w_i$	$[YT^{-1}]$	(\$/yr)
	N_i	$i = 1,2,3,4,5$	[-]	(# of persons)
		1 = # of supervisors needed in a factory	[-]	(# of persons)
		2 = # of engineers needed in a factory	[-]	(# of persons)
		3 = # of technicians needed in a factory	[-]	(# of persons)
		4 = # of workers needed in a factory	[-]	(# of persons)
		5 = Others	[-]	(# of persons)
	w_i	Annual wage for each group of labor	$[YT^{-1}]$	(\$/person/yr)
		$i = 1,2,3,4,5$		
3.	A	Area of land for factory	$[L^2]$	(miles^2)
4.	c_A	Unit cost of land	$[YL^{-2}]$	(\$/miles^2)
5.	$S = \sum_{i=1}^{3} R_i c_{R_i}$			
		Cost of feed materials	$[YT^{-1}]$	(\$/yr)
	R_i	$i = 1,2,3$		
		Annual amount of raw materials fed into the factory		
		1 = Fissile fuel	$[FT^{-1}]$	(tons/yr)

		2 = Co-60 radioisotopes--radiation sources	$[FLT^{-2}]$	(C_i/yr)
6.	R_3	3 = Processing materials	$[FT^{-1}]$	(tons/yr)
	c_{R_i}	i = 1,2,3		
		1 = Unit cost of fissile fuel	$[YF^{-1}]$	(\$/ton)
		2 = Unit cost of radioisotope	$[YF^{-1}L^{-1}T]$	$(\$/C_i)$
		3 = Unit cost of processing material	$[YF^{-1}]$	(\$/ton)
7.	C_D	Domestic capital	$[Y]$	(\$)
8.	C_F	Foreign capital (foreign loan)	$[Y]$	(\$)

$C = C_D + C_F$ The capital investment includes expenses of the first load of raw material, factory structures and equipment, construction facilities, engineering services, safety devices, public information and contingency. Sources of money come from domestic capital, export surplus, or available foreign loan.

9. O Annual production cost includes license fee, liability insurance, property insurances, property taxes, maintenance and operating supplies. Sources of money are the same as those of C $[YT^{-1}]$ (\$/yr)

10.	r_D	Domestic interest rate	$[T^{-1}]$	(%/yr)
11.	r_F	Foreign interest rate	$[T^{-1}]$	(%/yr)
	r_C	is the larger one between r_D and r_F	$[T^{-1}]$	(%/yr)
12.	P_A	Annual total agricultural productivity increase because of participation of nuclear technology	$[YT^{-1}]$	($/yr)
13.	P_I	Annual total industrial productivity increase because of participation of nuclear technology	$[YT^{-1}]$	($/yr)
14.	E	Electricity generated from the nuclear facility	[FL]	(Mw)
15.	c_E	Unit electricity price	$[YF^{-1}L^{-1}T^{-1}]$	(mills/kwh)
16.	L_f	Station load factor	[-]	(%)
17.	W	Annual amount of water produced by nuclear desalting plant	$[L^3T^{-1}]$	(cm^3/yr)
18.	c_W	Unit water price	$[YL^{-3}]$	($/$m^3$)
19.	c_M	Unit cost of processed material	$[YF^{-1}]$	($/ton)
20.	n	Station life time	[T]	(yr)

IV. DIMENSIONAL ANALYSIS TO FIND π-TERMS

On the basis of the original list of variables in Table 1, it follows that

$$B = F(N_t, N_L, N_e, w, A_t, A_a, A_m, A_d, A_r, A_s, c_A, c_W, R_f, T_m, R, c_R, P_A, P_I, c_F, H, f, F_r, F_t, c_p, I, E_x, G, I_p, r, r_i, E_m, U_c, E_c, E_t, c_E, L_f, r_e, T_h, N_p, N_h, c_s, n, Tr).$$

However, the original list of variables may be simplified to:

$$B = f(L, A, c_A, S, R_3, C_D, C_F, O, r_D, r_F, P_A, P_I, E, c_E, L_f, W, c_W, c_M, n)$$

Since there are 20 unknowns and 4 dimensions, the total number of variables may be reduced further to 16 by dimensional analysis. One possible set of dimensionless and independent π-terms may be written as

$$\frac{B}{C_D+C_F+c_A A} = f\left(\frac{P_A+P_I}{L}, \frac{P_I}{P_A}, \frac{O}{L}, \frac{r_D C_D + r_F C_F}{L}, \frac{r_F C_F}{r_D C_D}, \frac{C_D+C_F}{L\sum_{i=1}^{n}(1+r_C)^{-i}}, \frac{C_F}{C_D}, \frac{c_A A}{L\sum_{i=1}^{n}(1+r_C)^{-i}}, \sum_{i=1}^{n}(1+r_C)^{-i}, \frac{c_W W}{S}, \frac{c_E E}{S}, \frac{c_M R_3}{S}, L_f, \frac{c_W}{c_E}, \frac{c_M}{c_E}\right) \quad (1)$$

where

$\dfrac{B}{C_D+C_F+c_A A}$ is the ratio of benefit to investment;

$\frac{P_A+P_I}{L}$ is the total productivity per unit labor input;

$\frac{P_I}{P_A}$ is the ratio of industrial productivity to agricultural productivity. This also shows to what extent the country is industrialized;

$\frac{O}{L}$ is the operation and maintenance cost per unit labor input; or the production cost per unit labor input;

$\frac{r_D C_D + r_F C_F}{L}$ is the capital interest per unit labor input;

$\frac{r_F C_F}{r_D C_D}$ is the ratio of interest paid to foreign loan and domestic capital;

$\frac{C_D+C_F}{L \sum_{i=1}^{n} (1+r_C)^{-i}}$ is the investment per unit labor input in present worth;

$\frac{C_F}{C_D}$ is the ratio of foreign loan to domestic capital;

$\frac{c_A A}{L \sum_{i=1}^{n} (1+r_C)^{-i}}$ is the land cost per unit labor input in present worth;

$\sum_{i=1}^{n} (1+r_C)^{-i}$ is the present worth factor;

$\frac{c_W W}{S}$ is the sale of water gained from per unit raw material input;

$\frac{c_E E}{S}$ is the gross sale of electricity gained from per unit raw material input;

$\frac{c_M R_3}{S}$ is the sale of radiation processed material gained from per unit raw material input;

L_f is the station load factor;

$\frac{c_W}{c_E}$ is the ratio of water unit price to electricity unit price, or unit water price in terms of electricity price equivalent;

$\frac{c_M}{c_E}$ is the ratio of processed material unit price to electricity unit price, or unit processed material price in terms of electricity price equivalent.

V. DETERMINATION OF THE FUNCTION

In order to simplify the expression for the benefit, it is assumed to be separable into two components as indicated in Figure 2. The outer box (I) represents the overall system, and the inner box (II) represents the method or agent which performs the desired function or transformation. In this instance, it is a nuclear facility. Its performance is measured by its effectiveness G. It is assumed that the effectiveness function is mathematically separable from the benefit function for the total system. The functions for box (I) or (II) may be evaluated individually.

In box (I), Benefit

$$B = f_I(L,\ A,\ c_A,\ C_D,\ C_F,\ O,\ r_D,\ r_F,\ P_A,\ P_I,\ n,\ G) \tag{2}$$

From dimensional analysis, there are 13 unknowns and 3 dimensions: Y, L, T; hence, one possible equation in 10 variables is

$$\frac{B}{C_D+C_F+c_AA} = f_I\left(G,\ \frac{P_A+P_I}{L},\ \frac{P_I}{P_A},\ \frac{O}{L},\ \frac{r_DC_D+r_FC_F}{L},\ \frac{C_F}{C_D},\ \frac{r_FC_F}{r_DC_D},\ \frac{C_D+C_F}{L\sum_{i=1}^{n}(1+r_C)^{-i}},\ \frac{c_AA}{L\sum_{i=1}^{n}(1+r_C)^{-i}}\right) \tag{3}$$

where $\frac{B}{C_D+C_F+c_AA}$ is the ratio of benefit to investment in this case. Meanings of the other π-terms are as previously

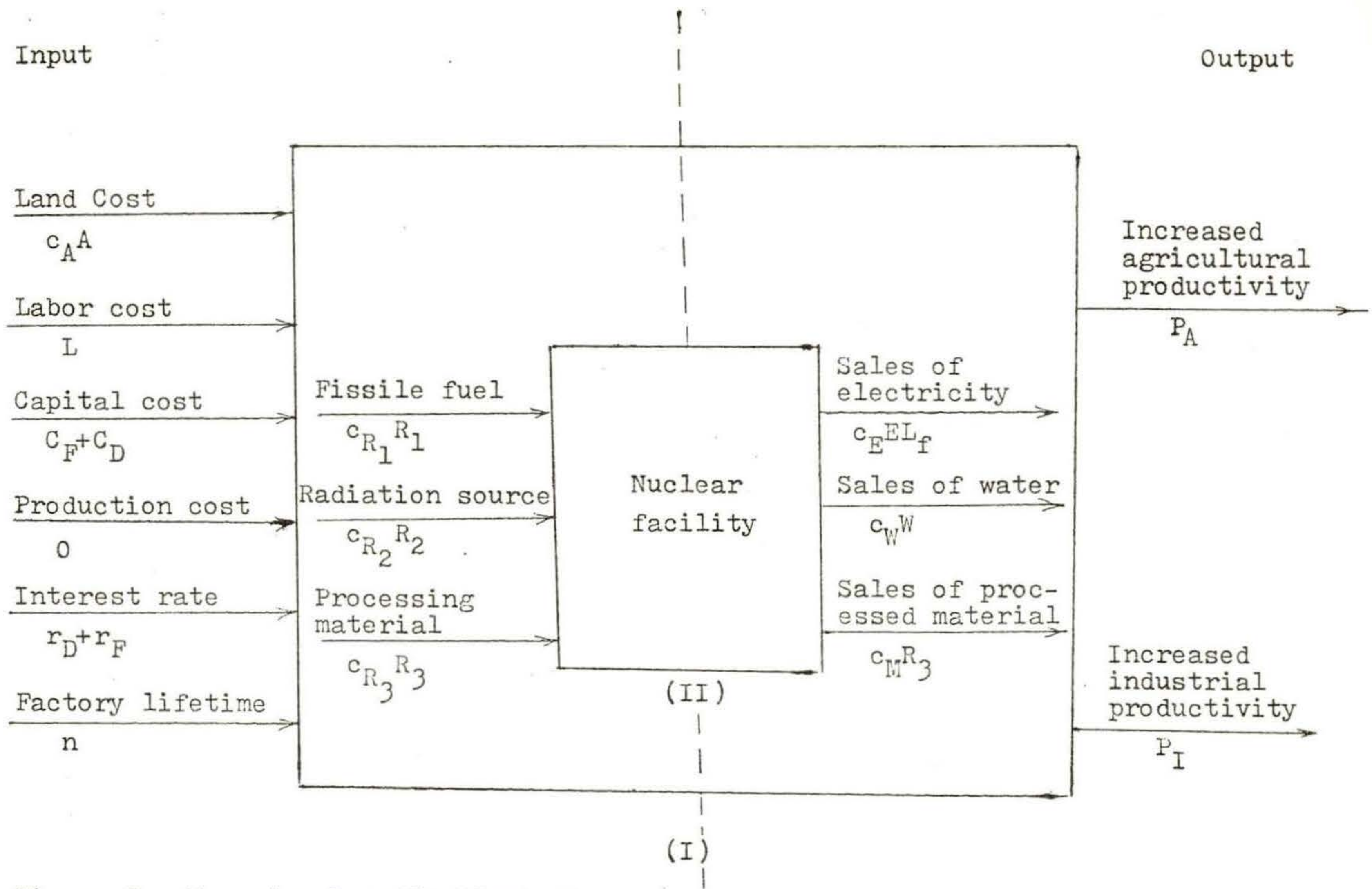

Figure 2. Two-step benefit block diagram

expressed. Furthermore, the profit is compared with cost on the basis of present worth. Assuming G is separable, the relationship may be expressed as

$$\frac{B}{C_D+C_F+c_A A} = G\,\frac{(P_A+P_I-L-O-(r_D C_D+r_F C_F))\sum_{i=1}^{n}(1+r_C)^{-i}}{C_D+C_F+c_A A}$$

To be conservative, r_C is picked up as the larger one between r_D and r_F.

In order to get components similar to π-terms, the numerator and denominator of the right hand side are divided by L respectively,

$$\frac{B}{C_D+C_F+c_A A} = G\,\frac{\left(\frac{P_A+P_I}{L}-\frac{O}{L}-\frac{r_D C_D+r_F C_F}{L}-1\right)\sum_{i=1}^{n}(1+r_C)^{-i}}{\frac{C_D+C_F}{L}+\frac{c_A A}{L}}$$

The present worth factor is moved from the nominator to denominator

$$\frac{B}{C_D+C_F+c_A A} = G\,\frac{\left(\frac{P_A+P_I}{L}-\frac{O}{L}-\frac{r_D C_D+r_F C_F}{L}-1\right)}{\frac{C_D+C_F}{L\sum_{i=1}^{n}(1+r_C)^{-i}}+\frac{c_A A}{L\sum_{i=1}^{n}(1+r_C)^{-i}}} \tag{4}$$

From equation 3:

$$f_I(G, \frac{P_A+P_I}{L}, \frac{P_I}{P_A}, \frac{O}{L}, \frac{r_D C_D + r_F C_F}{L}, \frac{r_F C_F}{r_D C_D}, \frac{C_D + C_F}{L \sum_{i=1}^{n} (1+r_C)^{-i}}, \frac{C_F}{C_D},$$

$$\frac{c_A A}{L \sum_{i=1}^{n} (1+r_C)^{-i}}) = Gf_I' (\frac{P_A+P_I}{L}, \frac{P_A}{P_I}, \frac{O}{L}, \frac{r_D C_D + r_F C_F}{L}, \frac{r_F C_F}{r_D C_D},$$

$$\frac{C_D + C_F}{L \sum_{i=1}^{n} (1+r_C)^{-i}}, \frac{C_F}{C_D}, \frac{c_A A}{L \sum_{i=1}^{n} (1+r_C)^{-i}}) =$$

$$G \frac{(\frac{P_A+P_I}{L} - \frac{O}{L} - \frac{r_D C_D + r_F C_F}{L} - 1)}{\frac{C_D + C_F}{L \sum_{i=1}^{n} (1+r_C)^{-i}} + \frac{c_A A}{L \sum_{i=1}^{n} (1+r_C)^{-i}}} \tag{5}$$

For more coherence between the left-hand side and right-hand side, equation 5 may be reordered in a better-looking way:

$$f_I (G, \frac{P_A}{L}, \frac{P_I}{L}, \frac{O}{L}, \frac{r_D C_D}{L}, \frac{r_F C_F}{L}, \frac{C_D}{L \sum_{i=1}^{n} (1+r_C)^{-i}}, \frac{C_F}{L \sum_{i=1}^{n} (1+r_C)^{-i}},$$

$$\frac{c_A A}{L \sum_{i=1}^{n} (1+r_C)^{-i}}) = Gf_I' =$$

$$G \frac{\frac{P_A}{L} + \frac{P_I}{L} - \frac{O}{L} - \frac{r_D C_D}{L} - \frac{r_F C_F}{L} - 1}{\frac{C_D}{L \sum_{i=1}^{n} (1+r_C)^{-i}} + \frac{C_F}{L \sum_{i=1}^{n} (1+r\ )^{-i}} + \frac{c_A A}{L \sum_{i=1}^{n} (1+r\ )^{-i}}} \tag{6}$$

and

$$f_I'\left(\frac{P_A}{L}, \frac{P_I}{L}, \frac{O}{L}, \frac{r_D C_D}{L}, \frac{r_F C_F}{L}, \frac{C_D}{L \sum_{i=1}^{n} (1+r_C)^{-i}}, \frac{C_F}{L \sum_{i=1}^{n} (1+r_C)^{-i}}\right.$$

$$\left.\frac{c_A A}{L \sum_{i=1}^{n} (1+r_C)^{-i}}\right) = \frac{\dfrac{P_A}{L} + \dfrac{P_I}{L} - \dfrac{O}{L} - \dfrac{r_D C_D}{L} - \dfrac{r_F C_F}{L} - 1}{\dfrac{C_D}{L \sum_{i=1}^{n} (1+r_C)^{-i}} + \dfrac{C_F}{L \sum_{i=1}^{n} (1+r_C)^{-i}} + \dfrac{c_A A}{L \sum_{i=1}^{n} (1+r_C)^{-i}}}$$

For the inner system, or method, the effectiveness is

$$G = f_{II}(S,\ E,\ L_f,\ W,\ c_E,\ c_W,\ c_M,\ R_3) \tag{7}$$

There are 9 unknowns and 4 dimensions: Y, L, T, F. By dimensional analysis a similar way is followed as for box (I),

$$G = \frac{B_{II}}{S} = f_{II}\left(\frac{c_W W}{S}, \frac{c_E E}{S}, \frac{c_M R_3}{S}, L_f\right) \tag{8}$$

The capital investment here is in terms of costs of all raw materials, defined by $S = \sum_{i=1}^{3} c_{R_i} R_i$ as mentioned before. The benefit B_{II} derives from sales of electricity, water and processed materials. Algebraically, $B_{II} = c_W W + c_E E L_f + c_M R_3$ and

$$G = \frac{B_{II}}{S} = \frac{c_W W + c_E E L_f + c_M R_3}{S} \tag{9}$$

Then

$$G = f_{II}\left(\frac{c_W W}{S}, \frac{c_E E}{S}, \frac{c_M R_3}{S}, L_f\right) = \frac{c_W W + c_E E L_f + c_M R_3}{S} =$$

$$\frac{c_W W}{S} + \frac{c_E E L_f}{S} + \frac{c_M R_3}{S} \tag{10}$$

From equations 4, 9, 1, the overall benefit to cost ratio becomes

$$\frac{B}{C_D+C_F+c_A A} = f\left(\frac{P_A+P_I}{L}, \frac{P_I}{P_A}, \frac{O}{L}, \frac{r_D C_D+r_F C_F}{L}, \frac{r_F C_F}{r_D C_D}, \frac{C_D+C_F}{L\sum_{i=1}^{n}(1+r_C)^{-i}},\right.$$

$$\frac{C_F}{C_D}, \frac{c_A A}{L\sum_{i=1}^{n}(1+r_C)^{-i}}, \sum_{i=1}^{n}(1+r_C)^{-i}, \frac{c_W W}{S}, \frac{c_E E}{S}, \frac{c_M R_3}{S}, L_f, \frac{c_W}{c_E},$$

$$\left.\frac{c_M}{c_E}\right) = f_I\left(G, \frac{P_A+P_I}{L}, \frac{P_I}{P_A}, \frac{O}{L}, \frac{r_D C_D+r_F C_F}{L}, \frac{r_F C_F}{r_D C_D}, \frac{C_D+C_F}{L\sum_{i=1}^{n}(1+r_C)^{-i}},\right.$$

$$\left.\frac{C_F}{C_D}, \frac{c_A A}{L\sum_{i=1}^{n}(1+r_C)^{-i}}\right) = G f_I'\left(\frac{P_A+P_I}{L}, \frac{P_I}{P_A}, \frac{O}{L}, \frac{r_D C_D+r_F C_F}{L}, \frac{r_F C_F}{r_D C_D},\right.$$

$$\left.\frac{C_D+C_F}{L\sum_{i=1}^{n}(1+r_C)^{-i}}, \frac{C_F}{C_D}, \frac{c_A A}{L\sum_{i=1}^{n}(1+r_C)^{-i}}\right) =$$

$$\left(\frac{\frac{P_A+P_I}{L} - \frac{O}{L} - \frac{r_D C_D+r_F C_F}{L} - 1}{\frac{C_D+C_F}{L\sum_{i=1}^{n}(1+r_C)^{-i}} + \frac{c_A A}{L\sum_{i=1}^{n}(1+r_C)^{-i}}}\right) \cdot \left(\frac{c_W W+c_E E L_f+c_M R_3}{S}\right) \tag{11}$$

VI. DISCUSSION OF THE EQUATION

There are some characteristics of equation 11:

1. Total investment should not equal zero, otherwise it is meaningless. $C_D+C_F+c_AA \neq 0$

2. Assume (P_A+P_I) is always larger or equal to $O+L+r_DC_D+r_FC_F$. For total benefit to investment ratio larger than or equal to 1, the nuclear technology is desirable. For if it is smaller than 1, it is not feasible to have a nuclear facility in the country.

3. L reflects the labor force in the country. If a country has a dense population and well-educated people, the labor cost will be less as long as she hires her own people. Otherwise, advanced engineers and talented supervisors have to be invited from other countries to provide assistance which means another loss of foreign exchange in addition to paying interest of foreign loans.

4. When a country asks for a loan, the offerer will go to survey the growth rate of her economy as well as the stability of her society in order to make sure that the money will be returned. So the breakdown of capital into domestic loan and foreign loan shows not only how available the foreign exchange but also how progressive the country expands to gain credits and confidence in the international market.

5. The interest rate has influence through two ways. One is the interest paid to the debtee, such as r_FC_F, r_DC_D; the

other shows in the inflation or cost of money such as appearing in the present worth factor.

6. Cost of land has a larger portion in capital of a nuclear power plant than that of isotope irradiation, because the former requires a population exclusive zone.

7. Where there is dry land, c_W usually will be relatively high. If the country has uranium mines, S will be different. If the country is rich in other commercial energy resources, the price of uranium will be relatively high and S goes up. Supply, demand and transportation of raw material determine S.

8. In the case of estimating the benefit from a nuclear power plant only, without desalting and radioisotopes, it is natural that $W = 0$, and $R_2 = R_3 = 0$.

9. Load factor will be determined by the fluctuation of demand in the country.

10. In case of dual purpose nuclear desalting plant, $R_2 = R_3 = 0$.

11. In case of food preservation, irradiation gives a longer shelf-life. The benefit includes equivalent dollar value due to more clearance or storage and better circulation of food within the country. Most developing countries have a high percentage of agricultural products in export. By the ability of longer preservation for agricultural products, it favors to export. Since there is no production of electricity and water, and uranium fuel is not used, $W = E = 0$, $R_1 = 0$.

12. In case of pest infestation, irradiation process

brings benefit in a similar way as that in food preservation except more fresh agricultural products rather than preserved ones coming out. Here again $W = E = 0$ and $R_1 = 0$.

13. For wood irradiation processes, apparently $W = E = 0$ and $R_1 = 0$. For the other radioisotope irradiation processes, no matter whether they are treating agriculture or industry, benefit can be obtained by following the above analysis.

VII. EXAMPLES

Two developing countries--Taiwan and India--are taken for case study. In Taiwan, a plan for a nuclear power plant located at Chinshan is evaluated. In India, a project of a dual-purpose nuclear power plant in Kutch-Saurashtra region is investigated.

A. Taiwan

Taiwan is an island about 140 miles off the southeast coast of the Chinese mainland. The 36,000 square kilometers of land area is densely populated, with millions inhabitants. Three-fifths of the total land is covered by mountains and forests. The rest is plains and hills. There is plenty of rain during summer. Although typhoons bring damage to the island, it does offer sufficient water for irrigation and electricity (Figure 3).

The present power system in Taiwan has a total installed capacity of 2720 Mw, including 901 Mw of hydro (28 stations) and 1819 Mw of thermal power (9 stations). More than 77% of the energy sold goes to industry. The system load is projected to increase at an average annual rate of 11.9% or to be tripled in 10 years.

Energy resources available for power production in Taiwan include sources of hydroelectric potential, coal, natural gas and possible geothermal steam and the imported energy of

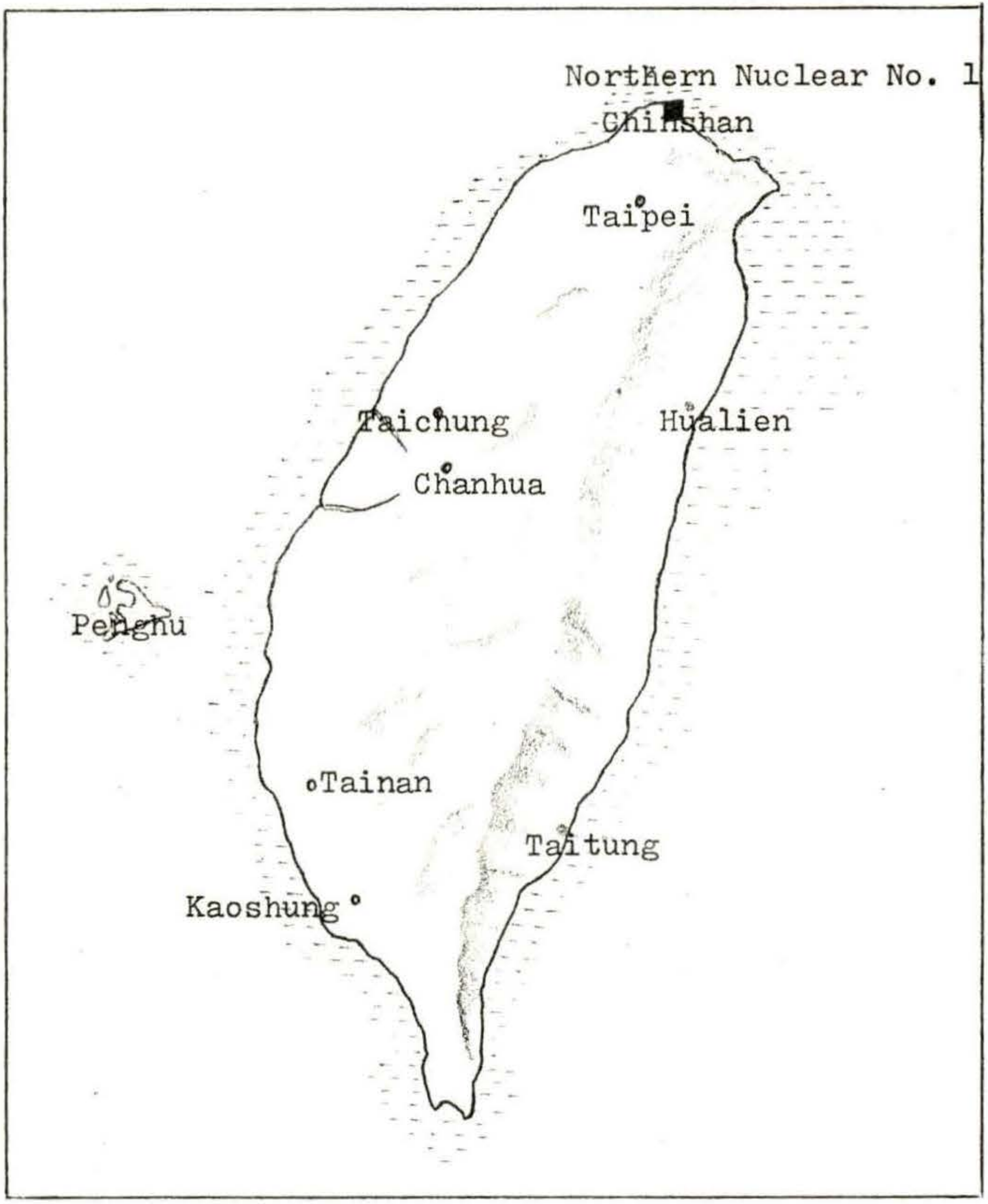

Figure 3. Taiwan

fossil and nuclear fuels. Survey of indigenous sources shows that they are insufficient to meet the energy requirements of the island. Eventually, the system load will have to rely on imported energy. Crude oil is practically all imported. Nuclear fuel deposits of commercial value are not found in Taiwan (17).

However, in September 1968, the Government has decided an annual growth of the average GNP as 8.5% and power growth of an average of 11.9% annually, and set an energy policy for the following 10 years, which indicated that the types and sources of the imported energy should be diversified because the country's economic energy supply will largely depend on importation. Nuclear fuels should be considered as the most important fuel in the long run. The Government also gave exemption of import duties on nuclear equipment and material.

A nuclear power plant located in the northern part of Taiwan starting to operate in 1975 was suggested by Taipower Company.

Investment and production costs of the plant are shown in Table 2.

In order to use equation 11, the following data are set from the information in Table 2.

The government had signed to allow borrowing 299.7 million from American Import-Export Bank with an interest rate of 8.125% (24). Hence, all the capital investment comes from a foreign loan.

Table 2. Data and cost estimation of planned nuclear power plant in Taiwan (5)

Item	Northern Nuclear No. 1
1. Rate capacity (MW)	636
2. Net capacity (MW)	604
3. Capacity factor (%)	83
4. Annual output (GWH)	4392
5. Project cost US $\$ \times 10^6$	167.5
6. Production cost (US Mills/kwh)	
Fixed charges	11.271%
Interest (8.5%)	3.242
Depreciation (1.271%)	0.485
Interim replacement (0.35%)	0.134
Tax & insurance	0.439
Subtotal (mills/kwh)	4.300
O & M (Organization & Methods)	0.290
Fuel	1.624

$C_D + C_F = C_F = C_F' + c_A A = 167.5$ million \$

where $C_F' = C_F - c_A A$, and $C_D = 0$.

The interest is $r_F C_F = 8.125\% \times 167.5 = 13.6$ million \$.

Production cost plus labor cost is $O + L = (4.3 + 0.29) \times 4392 \times 10^6 = 20.6$ million \$.

Assume $L = (6.72/93.28)O$, hence, $L = 1.85$ million \$, $O = 18.75$ million \$ (2).

The influence on agricultural and industrial productivity by nuclear technology in the future is based on previous year's economic experiences; in 1971

Mining	2,505 N.T.million \$
Manufacturing	50,550 N.T.million \$
Electricity, gas, water	4.431 N.T.million \$
Construction	10,191 N.T.million \$
Total industrial products	67,677 N.T.million \$
Annual electric energy sale	12,887 Gwh
Power consumption by industry	10,400 Gwh
Industrial portion of electricity consumption	0.808

Domestic consumption of electric power

In hydro-electric	1,177.7 coal eq. 1000 M/T
In thermal electric	4,944.6 coal eq. 1000 M/T
Domestic consumption of electric power	6,122.3 coal eq. 1000 M/T = 47,400 Gwh .

Nuclear power is predicted to be in mass production in Taiwan in 1975, in order to take into account inflation, the year 1971 may be used as the basis to estimate the dollar value in 1975 (22). With an annual growth of the average GNP as 8.5%, and power growth of an average of 11.9% annually, the dollar value due to sales of industrial products brought by unit electricity consumption in 1975 is (dollar value of industrial products per Gwh of electricity consumed) x (industrial portion of electricity consumed) x (annual output in Gwh of nuclear plant) x (inflation) x (foreign exchange from N.T.\$ to \$) x (portion of electricity investment among the total industrial investment). The last item for Taiwan is predicted as one half. The influence of electricity on agricultural productivity is little enough to be neglected. By substituting numbers in the above expression,

$$P_A + P_I = \frac{67{,}677 \text{ N.T. million \$}}{47{,}400 \text{ Gwh}} \times 0.808 \times 4392 \text{ Gwh}$$

$$\times \frac{(1+8.5\%)^4}{(1+11.9\%)^4} \times \frac{\$}{40 \text{ N.T. \$}} \times 50\%$$

$$= 43.5 \text{ million \$} \quad .$$

$r_D = 8.5\%$, since $r_D > r_F$, so $r_C = r_D = 8.5\%$

$n = 30$ years

$c_{R_1} = 1.624$ mills/kwh

$L_f = 83\%$

$c_E = 4.75$ cents/kwh

$$\frac{B}{C_D+C_F+c_A A} = G \frac{\dfrac{P_A+P_L}{L} - \dfrac{0}{L} - \dfrac{r_D C_D + r_F C_F}{L} - 1}{\dfrac{C_D+C_F}{L \sum_{i=1}^{n} (1+r_C)^{-i}} + \dfrac{c_A A}{L \sum_{i=1}^{n} (1+r_C)^{-i}}}$$

$$= G \frac{\dfrac{43.5}{1.85} - \dfrac{18.75}{1.85} - \dfrac{13.6}{1.85} - 1}{\dfrac{167.5}{11.1 \times 1.85}}$$

$$= 0.616 \text{ G}$$

$$G = \frac{c_W W + c_E E L_f + c_M R_3}{S}$$

$$W = R_3 = 0$$

$$R_2 = 0$$

$$S = c_1R_1 + c_2R_2 + c_3R_3 = c_1R_1$$

Hence

$$G = \frac{c_E EL_f}{c_1R_1} = \frac{47.5 \times 4392 \times 10^6 \times 30\%}{1.624 \times 636 \times 365 \times 24 \times 10^3} \times 6.9$$

Total benefit to investment ratio is $6.9 \times 0.616 = 4.25$

If it is divided by 30 years,

$$\frac{4.25}{30} = 0.142/\text{yr}.$$

B. Kutch-Saurashtra Region, India

India has 530 million of population. The total area is 1,261,817 square miles. She is the seventh largest country in area and the second most populous in the world. The Indo-Pakistani subcontinent has three main geographic regions: the northern mountain zone, the Indo-Gangetic Plain, and southern tableland. Within the Indo-Gangetic Plain, there is the Rann of Kutch which is in the southwest of the Thar Desert. The Rann of Kutch is a region of hard salt flats for half of the year (Figure 4).

There is a very acute shortage of water from conventional sources in this region. All it has is sea water along the coast. Most of the land is wasteful but is cultivatable.

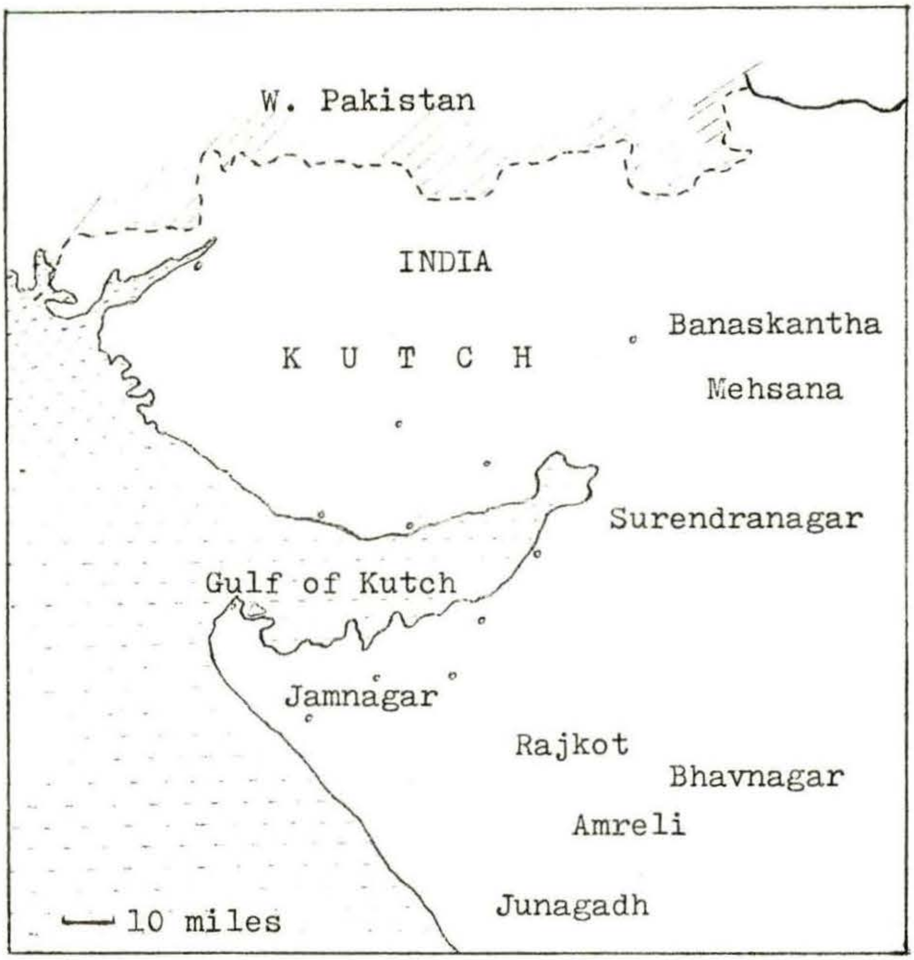

Figure 4. Kutch-Saurashtra Region, India

An agro-industrial complex project was suggested. The total design capacity of the dual-purpose plant is 1200 Mw(e) of net saleable power and 0.68 x 10^6 m^3/d (150 MGD) of desalted water. The agricultural block of the complex involves 16000 ha of cultivatable wasteland which would be reclaimed for cultivation. Table 3 gives the overall capital investment for the Kutch-Saurashtra project. Table 4 gives the overall annual expenses, profits and returns on investment for various constituents of the project.

Table 3. Agro-industrial complex: Kutch-Saurashtra region, overall capital investment (8)

Plant	Capital investment (10^6 Rs)	
	Foreign exchange	Total
1. Power plant	545.0	2725.0
2. Water plant	117.4	587.1
Total dual-purpose plant	662.4	3312.1
3. Fertilizer plants	406.8	1564.6
4. Aluminium industry	208.3	544.2
5. Caustic soda	28.3	70.4
6. Marine chemicals	--	9.9
Total industrial block	1305.8	5501.2
7. Water distribution system	0.2	53.0
8. Agricultural block	--	213.2
9. Transportation & storage facilities	--	823.8
10. Overall capital investment	1306.0	6591.2

Table 4. Agro-industrial complex: Kutch-Saurashtra region, overall annual expenses and profit (8)

Item	Annual expenses	Revenue from sales	Net profit	Return on investment (including interest) %
	--------------	million Rs	--------------	
1. Dual-purpose plant	431.6	407.7	-23.9	5.28
2. Fertilizer plants	655.4	1138.0	482.6	36.85
3. Aluminium plant	209.8	270.0	60.2	16.76
4. Caustic soda - HCl	28.0	33.5	5.5	13.78
5. Marine chemicals	4.3	8.9	4.6	52.5
6. Total industrial block	1329.1	1858.1	529.0	15.59
7. Agriculture	188.0	224.3	36.3	19.65
8. Overall complex	1517.1	2082.4	565.3	14.6

Following the above data:

P_A = 224.3 million Rs

P_I = 1858.1 million Rs

P_A+P_I = 2082.4 million Rs

$O + L$ = 1517.1 million Rs

C_D = 1306.0 million Rs

C_F = 6591.2 - 1306.0 = 5285.2 million Rs

r_D = 6%

r_F = 8% (24)

Assuming annual labor cost to be 6.72% of annual expenses (2),

$O + \frac{6.72}{93.28} \times O$ = 1517.2 million Rs

$1.072\ O$ = 1517.2 million Rs

O = 1415.1 million Rs

L = 1517.2 - 1415.1 = 102 million Rs

$r_DC_D + r_FC_F$ = 500.8 million Rs

C_D+C_F = 6591.2 million Rs

A = 16000 ha

c_A = 562 Rs/ha

c_AA = 9.0 million Rs

C_D has included c_AA already here

n = 25 yr

Since $r_F > r_D$, so $r_C = r_F$

r_C = 8%

$W = 0.68 \times 10^6\ m^3/d = 2.481 \times 10^8\ m^3/yr$

$c_W = 0.487\ Rs/m^3$

$E = 1200$ Mwe

$c_E = 0.30$ Rs/kwh (12)

$L_f = 85\%$

$$\sum_{i=1}^{25} (1+8\%)^{-i} = 10.6747$$

$$\frac{B}{C_D+C_F+c_A A} = G \frac{\frac{2082.4}{102} - \frac{1415.1}{102} - \frac{500.8}{102} - 1}{\frac{6591.2}{102 \times 10.6747}} = 0.1029\ G$$

$$G = \frac{c_W W + c_E E L_f + c_M R_3}{S}$$

$$S = c_1 R_1 + c_2 R_2 + c_3 R_3$$

$$R_2 = R_3 = 0$$

Hence $S = c_1 R_1$

$$G = \frac{c_W W + c_E E L_f}{c_1 R_1}$$

$$c_1 = 16 \text{ cents/MBTU} = \frac{0.16\$}{\text{MBTU}} \times \frac{\text{MBTU}}{0.293 \times 10^3 \text{kwh}} \times \frac{1}{30\%} \times \frac{7.5\text{Rs}}{\$}$$

$= 0.0137$ Rs/kwh (assume efficiency = 30%)

$EL_f = 1200 \times 10^3 \times 365 \times 24 \times 0.85 = 8.95 \times 10^9$ kwh/yr

$R_1 = 1200 \times 10^3 \times 365 \times 24 \times \frac{1}{30\%} = 35.05 \times 10^9$ kwh/yr

$c_1 R_1 = 0.0137 \times 35.05 \times 10^9 = 480$ million Rs/yr

$c_E EL_f = 0.30 \times 8.95 \times 10^9 = 2690$ million Rs

$c_W W = 0.487 \times 2.481 \times 10^8 = 121$ million Rs

$$G = \frac{121 + 2690}{480} = 5.85$$

$$\frac{B}{C_D + C_F + c_A A} = 5.85 \times 0.1029 = 0.6$$

This ratio 0.6 is shared within 25 years. Hence for each year, the benefit-to-cost ratio is

$$\frac{0.6}{25} = 0.024/\mathrm{yr} \quad .$$

VIII. COMPARISON BETWEEN THE RESULTS FROM TWO EXAMPLES

It has been shown that the benefit to cost ratio of a nuclear power plant at Chinshan in Taiwan is quite high--predicted to be 4.25 at the end of 30 years--while that of a dual-purpose nuclear plant in Kutch-Saurashtra in India, on the other hand, is rather low--only found to be 0.6 at the end of 25 years.

One possible reason for such high benefit in Taiwan might result from her ever-growing accelerated expansion of industry and therefore inducing a large demand for electricity. If there is enough electricity supply to meet the ever-increasing need from industry, it is not hard to foresee that the money earned from undustrial products in the future will be much more than that originally invested in nuclear power plant today.

Another reason is due to current unit price of electricity being much higher than the other country's so that it can meet more expenditure for nuclear power.

In India, the benefit to cost ratio is 0.6. This means when one dollar is invested, only fifty cents can be returned.

Although for these two different countries, different nuclear technology is selected and situations are quite different, the benefit to cost ratios still can be compared.

In summary, Taiwan is a better place to adopt nuclear power plant, and it is still not the time for India to use nuclear energy for both electricity and desalination.

IX. CONCLUSION AND FUTURE WORK

It is a new trail to merge environmental factors into quantitative research of nuclear technology. As a matter of fact, only through this way could science and engineering be realistically practiced. The calculated benefit out of particular nuclear technique differs very much from country to country as is shown in two examples. It manifests the feasibility and desirability of using nuclear technology regardless if the country wants that just for the sake of prestige or only to get experience.

Highlight of this thesis is the prediction of agricultural and industrial productivity increase due to the participation of nuclear technology. This work needs to take into consideration the detailed influential components in agriculture and industry in the future as in the past, in indigenous resources as in human endeavors.

It is the author's hope that results from benefit estimation here may help the decision-making of governors in developing countries as far as they are going to consider nuclear technology. Detailed calculations in using nuclear power plant or nuclear dual-purpose plant have been done. More work can be put into efforts regarding radioisotope utilization which, in the author's thought, is promising and appreciable for developing countries.

X. LITERATURE CITED

1. P. C. Aebersold, "Advances in Radioisotope Production and Utilization in Science and Industry," Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy, Geneva, United Nations, Sept 1964, 15, 201-211, 1965.

2. A. F. Alfred, Notes of Nuc. E. 524, "Nuclear Power Economics," Ames, Iowa, Department of Nuclear Engineering, Iowa State University, 1973.

3. F. S. Aschner, S. Yiftah and P. Glueckstern, "Technical and Economic Problems of Large Dual-Purpose Plants for Power Generation and Sea Water Desalination," TNSD-118, Technion - Israel Institute of Technology, Department of Nuclear Science, Haifa, Feb 1966.

4. H. Broeshart, C. M. Cho, L. E. Engelbert, L. E. Ericson, M. Fried, H. Goresline, J. Keller, K. Milaelsen, J. Moustgaard, B. Sigurbjörsson and P. B. Vose, "Advances in the Use of Isotopes and Radiation Sources in Agriculture and Food Science," Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy, Geneva, United Nations, Sept 1964, 15, 264-274, 1965.

5. D.S.L. Chu, "Integration of the Second Nuclear Power Plant in the Electrical Network of Taiwan, Republic of China, as a Means of Lowering the Cost of Delivered Power, A/CONF.49/P/803, Proceedings of the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva, United Nations and the International Atomic Energy Agency, Sept 1971, 14, 61-72, 1972.

6. A. Fouad, "A Symposium on Technology and Social Change in Foreign Cultures," Ames, Iowa, Iowa State University, Feb 1973.

7. E. E. Fowler, "Recent Advances in Applications of Isotopes and Radiation in the United States of America," A/CONF.49/P/840, Proceedings of the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva, United Nations and the International Atomic Energy Agency, Sept 1971, 14, 29-43, 1972.

8. V. K. Iya, A. C. Eapen, and K. Krishnamurthy, "Applications of Radioisotopes and Radiation Sources in Industry, Radiation Processing and Hydrology, Current Status in India," A/CONF.49/P/539, Proceedings of the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva,

United Nations and the International Atomic Energy Agency, Sept 1971, 14, 3-17, 1972.

9. B. Kelin, "A Survey of Desalination by Reverse Osmosis," 67-UNT-7, The Underwater Technology Conference, Hampton, Va., May 1967, American Society of Mechanical Engineers, 1-8, Feb 1967.

10. M. A. Khan, "Nuclear Power and Developing Countries," IAEA Bulletin, 14, No. 3, 11-17, 1972.

11. W. R. Marshall, Jr., "Social Directions for Technology," Commission on Education, National Academy of Engineering, Washington, D.C., June 1971.

12. R. S. Shinn, J. B. Folan, M. G. Hopkins, N. B. Parker and R. L. Younglof, "Area Handbook for India," U.S. Government Printing Office, Washington, D.C., May 1970.

13. M. S. Swaminathan, "The Role of Nuclear Techniques in Agricultural Research in Developing Countries," A/CONF.49/P/768, Proceedings of the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva, United Nations and the International Atomic Energy Agency, Sept 1971, 12, 3-32, 1972.

14. K. T. Thomas, N.S.S. Rajan and M.P.S. Ramani, "Prospects and Planning for Nuclear-Powered Agro-Industrial Complexes in India," A/CONF.49/P/529, Proceedings of the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva, United Nations and the International Atomic Energy Agency, Sept 1971, 6, 131-153, 1972.

15. M. Willrich, "Global Politics of Nuclear Energy," Praeger Publishers, Inc., New York, 1971.

16. G. M. Urrows, "Nuclear Energy for Desalting," One of a Series on Understanding the Atom, U.S. Atomic Energy Commission, Division of Technical Information, Sept 1967.

17. "Almanac of Republic of China," Society of Almanac of Republic of China, Taipei, Taiwan, Dec 1972.

18. "Application of Food Irradiation in Developing Countries," STI/DOC/10/54, Technical Reports Series No. 54, IAEA, Vienna, 1966.

19. "Costing Methods for Nuclear Desalination," STI/DOC/10/69, Technical Reports Series No. 69, IAEA, Vienna, 1966.

20. "Guide to the Costing of Water from Nuclear Desalination Plants," STI/DOC/10/80, Technical Reports Series No. 80, IAEA, Vienna, 1967.

21. "Progress and Future Tasks in Food Irradiation," IAEA Bulletin, 15, No. 1, 2-9, 1972.

22. "Taiwan Economic Statistics," Industry of Free China, 38, No. 6, 39-193, Dec 1972.

23. "Ten-Year Plan for Development", Free China Review, 22, No. 3, 55, Mar 1972.

24. "World Bank", International Development Association, Washington, D.Cl, 1972.

25. "World/Economy of the World", The World Book Encyclopedia, W-X-Y-Z, 21, 350b, Field Enterprises Education Corporation, Chicago, 1972.

XI. ACKNOWLEDGMENTS

The author wishes to acknowledge her gratitude to Dr. Glenn Murphy, Distinguished Professor of Engineering, for his interest and encouragement throughout this study.

The author also appreciates very much the help from Dr. Alfred F. Rohach and Dr. Maurice A. Larson, of the Department of Chemical Engineering and Nuclear Engineering.

Special gratitude is expressed to Mr. Pei-Keng Chu, father of the author, who has supplied much information from Taiwan as well as moral support.